Automatic Station for Continuous Monitoring of Environmental Radiation

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Abstract – **The problems concerning design of an automatic station for continuous monitoring of the environmental radiation are described. The structure of the station is presented as well as the implemented principles, methods and operation modes. Some problems arising from the continuous operation mode under open atmospheric conditions are also discussed.**

Keywords* – *Continuous measurements, absorbed dose-rate, logarithmic energy spectrum

I. Introduction

The actuality of the problem for continuous measurement and monitoring of the environmental radiation is still more increasing in the last years due to the frequently occuring armed conflicts, terrorists attacs, potential accidents in nuclear power plants etc. [1]. There are three main difficulties in this respect:

- the deficiency of equipment possessing high sensitivity and precision in order to measure near-background radiation level; (to achieve the necessary accuracy the energy distribution of the radiation has also to be taken into account);
- the increased requirements to the equipment working at heavy conditions – continuous outdoor operation in a wide temperature interval, precipitation etc.;
- the high price of the commercial equipment which can in part satisfy the above requirements.

A possible way to achieve both high sensitivity and high accuracy in a wide dose-rate range is to use two detector systems. The low levels are then measured by high sensitive detectors (e.g. based on NaI(Tl) scintillators) and the high dose rates – by ionisation detectors [1].

The progress in the electronic components during the laste decade has made possible to develop portable spectrometric systems having lower power requirements and lower price [2,3]. They can serve as a basis for high sensitive systems for continuous monitoring which conform with the above mentioned requirements.

The automatic station suggested in the present work is based on a portable multichannel analyser with a logarithmic energy scale [3]. It uses single detector system with a 3x3” NaI(Tl) crystal and two measurement modes.

The dose rate for weak radiation fields is determined by means of the spectrometric data collected during the measurement.

In the case of high radiation intensity (when the dead time of the spectrometric channel is considerably large) the dose rate is determined by the information generated from the radiometric channel which is a single-channel spectrometer with variable energy threshold (in order to flatten the energy dependence of the dose).

II Design

A generalised structural scheme of the automatic station is shown on Fig.1. It contains the following main blocks:

A. Detector module

A scintillation crystal $\varnothing 3\times 3''$ is used combined with a FEU82 (Russia) photomultiplier.

B. Detector power supply

A diode-capacitive Cockroft-Walton multiplier is used to supply the PMT dynode system. A LM2578 pulse stabiliser is used which can directly stabilise negative voltage [4]. The dynode potentials are controlled by changing the value of a control voltage generated by integrating the PWM1 output signal of the used microcontroller. In this way, the PMT operation mode can be software controlled.

Total energy consumtion of the high voltage converter does not exceed 4mA at 12V source supply.

C. Spectrometric channel

The detector output signals are shaped and selected by a resonant charge-code converter [5]. Its operation principle is based on the idea to use a LC circuit as a load in the PMT anode chain and to count the maxima (or minima) of the generated fading oscillations until they ‘sink’ under a predefined reference level. The number of the counts serves then as a code to sort the event registered by the detector according to its energy. This addressing method is very simple; however, the channel numbers are proportional to the energy logarithm instead to the energy itself.

The number of the useful channels in such a multichannel analyser depends on the LC circuit’s quality factor. It can be improved by a partial compensation of the energy dissipated inside the LC circuit. If a positive feedback is introduced, 256 channels of the spectrometer are achieved.

The pulses coming from the detector during the conversion time of the spectrometer are switched over to the radiometric channel using a differential current switch. In this

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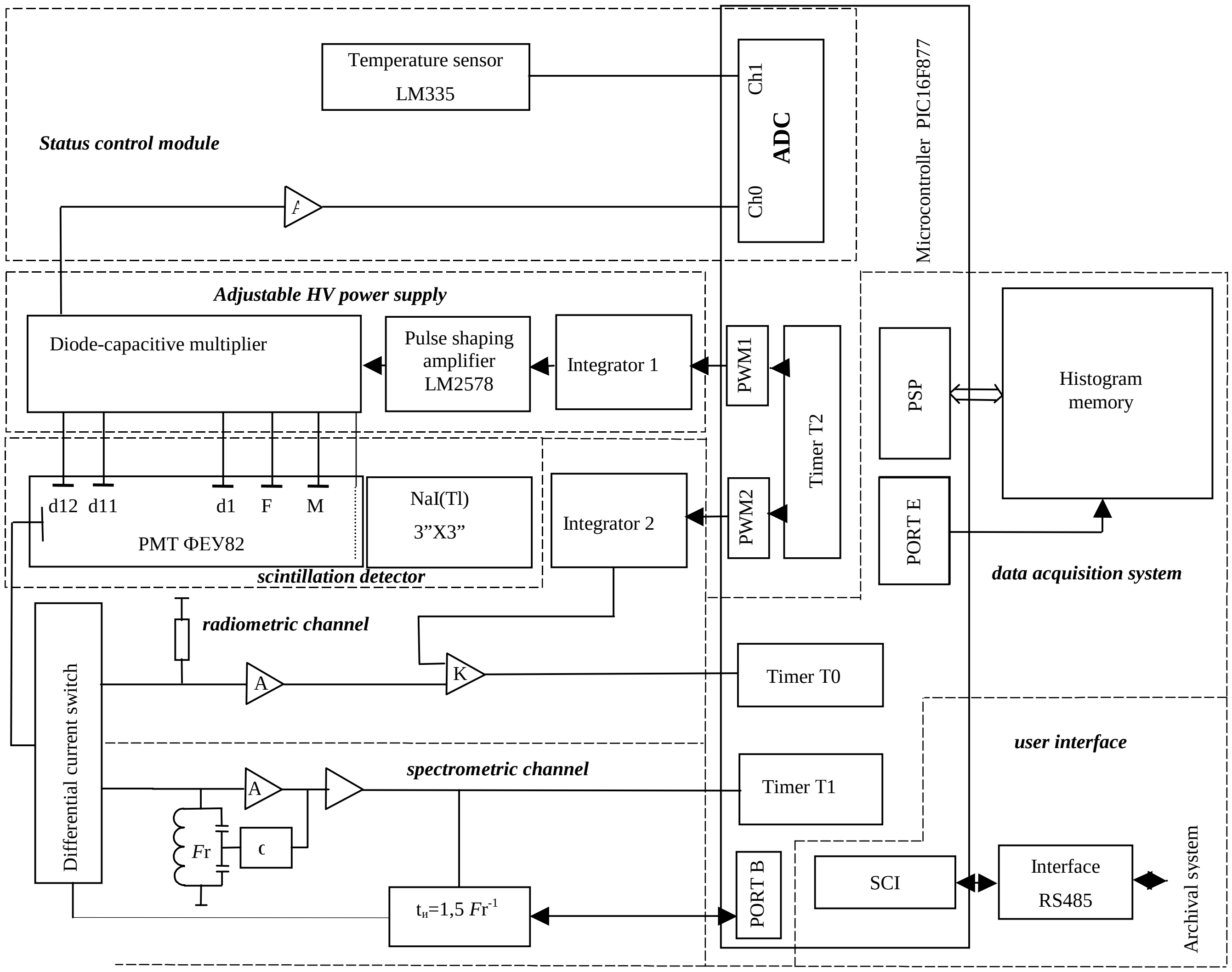

Fig. 1

way it is possible to account for the events lost during the dead time of the spectrometer channel.

D. Radiometric channel

The radiometric channel comprises of a linear amplifier of the PMT anode pulses and a comparator which converts them to standard CMOS levels. The comparator’s threshold is controlled by the output voltage of a second integrator following the PWM2 output of the used microcontroller. So, it can be also controlled by the software.

If the count rate of the incoming pulses is low, the spectrometric mode is preferred. A low level value is given the comparator’s threshold, so that all events entering the detector during the spectrometer’s dead time are registered by the radiometric channel.

At higher count rates the dose is determined only by the radiometric channel. In that case, all pulses are switched to the radiometric channel via the differential current switch and the comparator’s threshold is being varied so that the dose rate can be calculated by the JAERI method [6].

E. Data Acquisition System

The data acquisition system is based on a single chip microcontroller PIC16F877 of MicroChip and it uses extensively its peripheral systems.

Timer2 is used to generate the main time intervals of the system. It is used also in the two PWM pulse generators which control the PMT high voltage (PWM1) and the radiometric comparator’s level (PWM2).

All shaped pulses bursts coming from the spectrometric channel are counted by the Timer1 which works in burst mode. The timer output code is used as address for sorting the current event into the spectrometric (histogram) memory.

The spectrometric memory is 128 kbyte. Its schematic is designed to exchange up to 16 bytes in burst mode. The memory contains up to 240 spectrograms which allows a long time standalone work of the system.

Timer0 is used to register the pulses coming from the radiometric channel.

Port B is used in interrupt mode to receive end-of-burst signal from the spectrometric subsystem. It can also control the differential current switch to redirect all the PMT anode pulses to the radiometric channel.

F. Interface

All data collected in the automatic station are transferred to a higher hierarchy control level in NRZ format via the serial communication interface (SCI) embedded in the microcontroller. All electric signals are RS485 compliant. The latter interface is preferred by two reasons:

- it ensures stable work at relative longer distances to the archiving station;
- it allows parallel operation of several units (such as a meteosattion, for example).

G. Status control

A status control channel is foreseen in the automatic station to monitor some of its current parameters.

The ADC embedded into the microcontroller is used to measure the current value of the PMT voltage (the potential between the anode and the last dynode which is proportional to the whole voltage supplied to PMT).

The temperature of the scintillation detector is also measured. The used sensor is of type LM335; it has sensitivity 10 mV/K, thus allowing a discretisation step of 0.5 ^{o}C.

H. Power supply of the station

The continuous operation mode of the automatic station sets strong requirements regarding the power supply module. All necessary voltage supply is taken from a pulse DC-DC converter (not shown in Fig.1) powered by 9-24V DC. The total energy consumption of the station does not exceed 90mA at 12V in all modes of operation.

The power for the DC-DC converter is received from a 220 V~ /12 V= AC-DC converter backed up by a 12V/3.2Ah lead accumulator. The load characteristic of the AC-DC converter is limited by output current to 400mA and by output voltage at 13.8V. Thus, an optimal recharging mode of the used accumulator is guaranteed. In case of power net failure the automatic station can work more than 24h with the backup accumulator.

III Operation modes

A. Determination of the dose rate in the spectrometric mode

The dose absorbed within the detector volume is determined by means of the spectral distribution of the registered gamma-rays. The charge appearing at the PMT anode is proportional to the energy deposited in the detector and it is independent on the kind of the interaction. The dose absorbed for the time interval of the measurement is:

$$D = k_d \cdot \sum_{I_{\min}}^{I_{\max}} N(I).E(I) \qquad (1)$$

where N(I) is the number of counts registered in the I-th channel;

E(I) is the average energy corresponding to the I-th channel;

k_d is a coefficient to account for the detector mass and geometry.

An advantage of this method is its high accuracy and sensitivity which are superior to any other methods at low dose rates (i.e. close to the natural background).

B. Determination of dose rate in the radiometric mode

At higher count rates the dead time of the resonant charge-code converter becomes rather high and causes considerable measurement errors. It is provided to use the radiometric channel in this case, when all PMT signals are redirected to that channel (by the differential current switch).

In this case, the method of the so called spectral weight function G(E) is used for dose calculations [6]. G(E) is indeed a conversion operator connecting the absorbed dose with the pulses distribution by:

$$D = \int_{E_{\min}}^{E_{\max}} F(E).G(E)dE \qquad (2)$$

where F(E) is the spectral distribution of the registered events in the energy range E_{min} - E_{max}.

In the measurement, the operator G(E) is replaced with a time dependent operator G(t), which repeats its characteristic during the integration time interval. This is made using the programmable threshold of the integral discriminator (the comparator in the radiometric channel):

$$D = k_d \int_{E\,\min}^{E_{\max}} N(E).G(E)dE = k_d^t . \sum_{t_{\min}}^{t_{\max}} N(t).G(t) \qquad (3)$$

Here again k_d^t accounts for the detector characteristics.

In this case the automatic system works as a single-channel analyser. So, the length of the integration time interval $t_{\max} - t_{\min}$ should be sufficiently short (several seconds) to follow the dynamics of the radiation field. In fact, the time cycle in (3) is continuously repeated.

This method allows measurement of dose levels which are considerably higher than those achievable by the multichannel spectrometric method without replacing the detector system.

IV Problems arisig from continuous operation

The automatic station is designed for long term continuous outdoor work. The measurement conditions set additional requirements regarding its stability and reliability. Some of the more essential resulting problems are:

A. Temperature drift

The outdoor operation implies a temperature change in a very large interval (at least -20^{o}C to +40^{o}C). The temperature drift of the scintillation detectors is well pronounced. It is due mainly to the PMT instability. Hence, a stabilisation system is required to compensate temperature drift. In our system the temperature drift has been separately studied and the PMT high voltage supply is tuned during the operation using the temperature value measured continuously at the detector system.

B. Long term instability

The long term instability of the spectrometric systems is usually defined for 16h continuous work at count rate 1000 cps and constant operation conditions (temperature, power supply etc. [7]).

The long term continuous operation requires even stronger stability. For example, the change of the ambient air humidity influences the capacitive multiplier work and then it changes the overall PMT gain. Some additional constructive precautions have been taken to avoid that effect: the high resistance part of the PMT supply is carefully varnished and some absorbing substance is put into the hermetised volume (silica gel).

The ageing of the components also influences the long term stability of the system, e.g. the degradation of the last PMT dynode can decrease the anode current by 50-80% for 1000h operation.

Hence, an additional method for active stabilisation is required. A general solution is to control the centroid of the spectral line of a known isotope; the best candidate is the naturally occuring ^{40}K. This method is not applicable in some specific cases – if the reference line is masked by stronger lines in its vicinity (e.g. ^{60}Co). Then the active stabilisation is bypassed.

C. Power supply backup

The used power supply scheme allows continuous operation of the system for more than 24h without external power source.

V Construction features

The used non-standard spectrometer design makes possible to assemble the whole automatic system inside a single hermetic cylindrical container of magnetic soft material with outer dimensions $\varnothing 115 \times 300 mm$ (including the scintillator). It has a 4-wires connection: two for the DC power supply and two for the interface.

VI. Conclusion

Usually, the systems for radiation monitoring are based on doubled detector system – one high sensitive detector is used for the low doses and another – for elevated doses.

Combining a spectrometric method with that of the pulse height weighting function [6] makes possible to use the same detector for both high and low radiation fields keeping good accuracy and sensitivity in a large dose scale.

System parameters:

Detector system background	< 20 nGy/h
Energy range	50 keV – 10 MeV
Pulse height analysis	resonant charge-code converter at 1MHz, 256 channels
Conversion time	(4.4 + N.1) μs – N is the channel number
Histogram memory	128kB, 2^{16}-1 counts per channel, up to 240 spectra.
Dead time correction	counting the lost pulses

Adjustments
Automatic acquisition cycle – 0.01s to 167772s, step 10 ms
Hardware adjustment of the energy scale slope
HV adjustment – programmable, 500-2000 V, 1024 steps

Control interface - RS485

Power supply – 12V DC

Power consumption – < 100mA.

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